Development of Intelligent Processing Methodology for Intermetallic Matrix Composites

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Progress Report #1

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1.0 INTRODUCTION

It is proposed to develop processing tools for a broad, new family of *in*-situ metal matrix composites based upon the innovative use of multilithic reinforcement strategies. Intermetallic matrix composites (IMCs), reinforced with a dispersed ceramic phase, will be incorporated into metallic matrices to serve as reinforcing entities within the resulting multilithic reinforced composite (MRC). IMC-reinforcement in metallic matrices is particularly novel since they can be created to possess low temperature strengths normally unique to structural ceramics, and retain a metallic-like ability to be deformed at high temperatures. When combined with creative processing methodologies, such composites will offer an unprecedented degree of microstructural and property design capability. When specifically applied to light-metal matrices, the composites will possess the normally elusive combination of high specific strength, thermomechanical stability, economy of processing, and increased use-temperature capability.

While the concept of an IMC-reinforced metal matrix composite can be broadly extended to a wide range of conceivable processing methodologies and composite geometries, *deformation processing techniques* has been selected for this effort as the approach whereby the best properties of both the IMC and matrix components can be most efficiently and synergistically applied. For example, through the imposition of high temperature, powder-based extrusion, an aligned MRC can be created if the metal matrix and the IMC-reinforcement deform commensurably.

2.0 OBJECTIVES

The specific objectives of this study are to:

1. Identify most significant MRC material system(s) for advanced navy propulsion systems.

2. Develop and demonstrate feasibility of using advanced material process modeling to establish the conditions of extrusion whereby commensurate flow of a metal and a discontinuously-reinforced IMC can be achieved.

3. Scale-up process to determine the most cost-effective deformation processing route (extrusion, forging) for production of MRC materials.

4. Perform market analysis to establish a database for commercialization of MRC materials.

3.0 PROGRESS AND STATUS

Task 1 Identification of Most Significant MRC Materials Systems for Advanced Navy Propulsion Applications

Initial discussions have been conducted by the MATSYS - Pratt and Whitney - Dynamet IPPD team to define the MRC materials and properties required to meet advanced naval propulsion system requirements, and to specify components which would serve as candidates for MRC materials insertion. Materials systems of general interest include MRC materials with matrices of alpha and beta phase titanium alloys, and potentially, high temperature aluminum and nickel-based superalloys.

This subgroup will continue its analysis, and recommend MRC materials and components to guide the research and development activities of the overall team.

Task 2 Process Model Development, Implementation and Validation

The effort has focused upon co-deformation processing of metal/IMC blends based upon two variants of the Ti-6Al-4V + (Ti-Al + TiB_2) MRC material system. The objective of this activity is to determine the processing conditions whereby an IMC will commensurately deform when processed within a ductile metal matrix.

Extrusion trials were conducted to assess whether a high strength IMC is capable of commensurate deformation within a metallic matrix. Results of the co-deformation trials are illustrated in Figure 3-1. The trials demonstrated that a high strength, high aspect ratio IMC "fiber" can be produced *in-situ* within a metallic matrix. Based upon the results of those brief trials, it is now appropriate to examine the numerous means by which the composite microstructure can be optimized and customized for specific applications or performance needs. Specifically, analysis is required which will allow one to define conditions (processing and microstructural) whereby the homogeneity of deformation can be maximized across the cross section and all present components and particles. Further, the ability to specifically "design" the fibrous IMC introduces the ability to create composites with broad property (e.g., strength, modulus, ductility, toughness) ranges. For example, co-deformability will be influenced by the volume percentage, size, and flow stress of the IMC; the latter can be independently scaled by varying the matrix composition, the volume percent of TiB_2, and the temperature and rate of processing. The resulting MRC properties will rely upon the properties and distribution of the IMC incorporated.

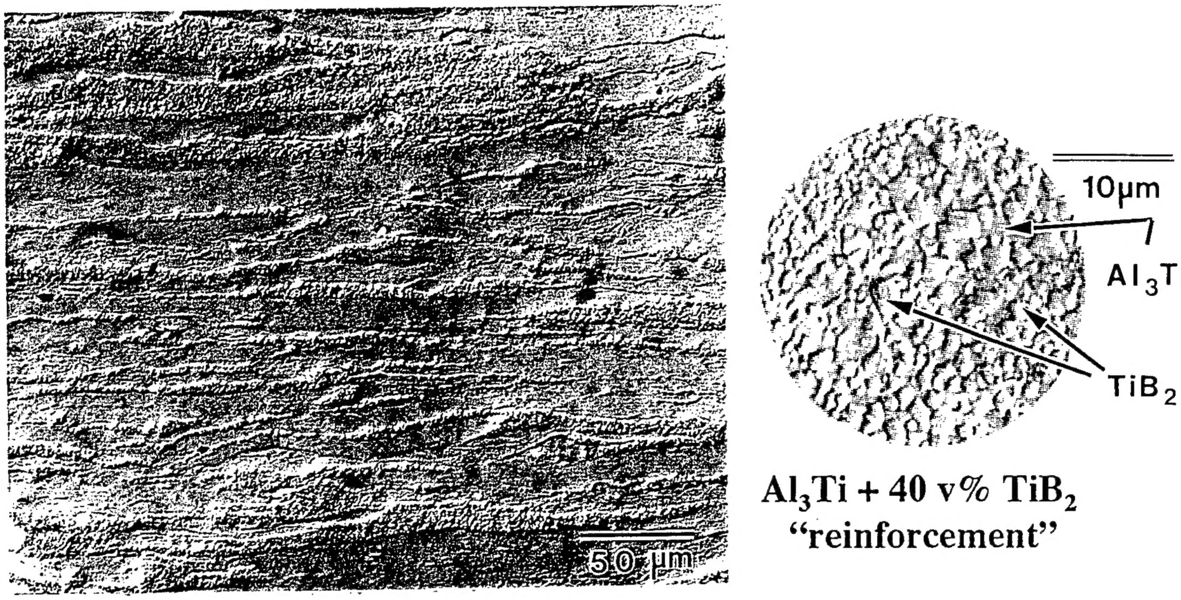

Figure 3-1. Ti-6Al-4V + 40 v% (Al_3Ti+40 v% TiB_2) MRC produced via extrusion at 1200°C and an extrusion ratio of 16:1. As shown, the IMC has deformed with the metallic matrix. Higher magnifications (right) shows the dispersed TiB_2 within the intermetallic matrix.

While most high strength, reinforcing-capable IMCs would be expected to have significantly higher flow stresses than any candidate metal component at low-to-moderate temperatures, the mechanical incompatibility rapidly disappears and converges at high temperatures creating the opportunity to "co-process" the two as components of a composite. In Figure 3-2 the high temperature flow behavior of two candidate intermetallic matrices (near-γ TiAl and Al_3Ti) reinforced with high volume fractions of TiB_2, 30, 40, and 50 volume percent, is compared to that of Ti-6Al-4V, a candidate metallic matrix for the resulting composite.

To identify processing conditions, flow behavior at equal Z, Zener-Holloman parameter, and stress is examined. For the Ti-6Al-4V matrix reinforced with $TiAl_3$ + 50v% TiB_2 IMC the temperature (1200°C) and rate of extrusion (5 mm/s) are selected, as illustrated in Figure 3-3.

Efforts are underway to establish a physically faithful process model to simulate extrusion. During the extrusion of an aggregate of powders it is necessary to consider the strain distribution within multiple phases. The modeling effort will identify conditions

whereby the deformation of the two constituents will occur at similar rates within the extrusion process zone, thus leading to fully-compatible (fully-commensurate) co-deformation. Micromechanics, mechanism-based models will be used to simulate the extrusion process and optimize processing conditions. These models were developed for monolithic material and are being modified to enable simulation of composite materials. This effort will be coordinated with work currently underway by Prof. Ashby and his colleagues where models are being developed for compaction of composite materials.

The models need to account for (1) processing conditions, such as temperature, extrusion ratio, extrusion rate, extrusion die and canister design, and (2) possible composite architectural variables which can be varied to independently influence co-deformability and property evolution of MRCs, such as MMC matrix composition, and IMC matrix composition and volume percentage.

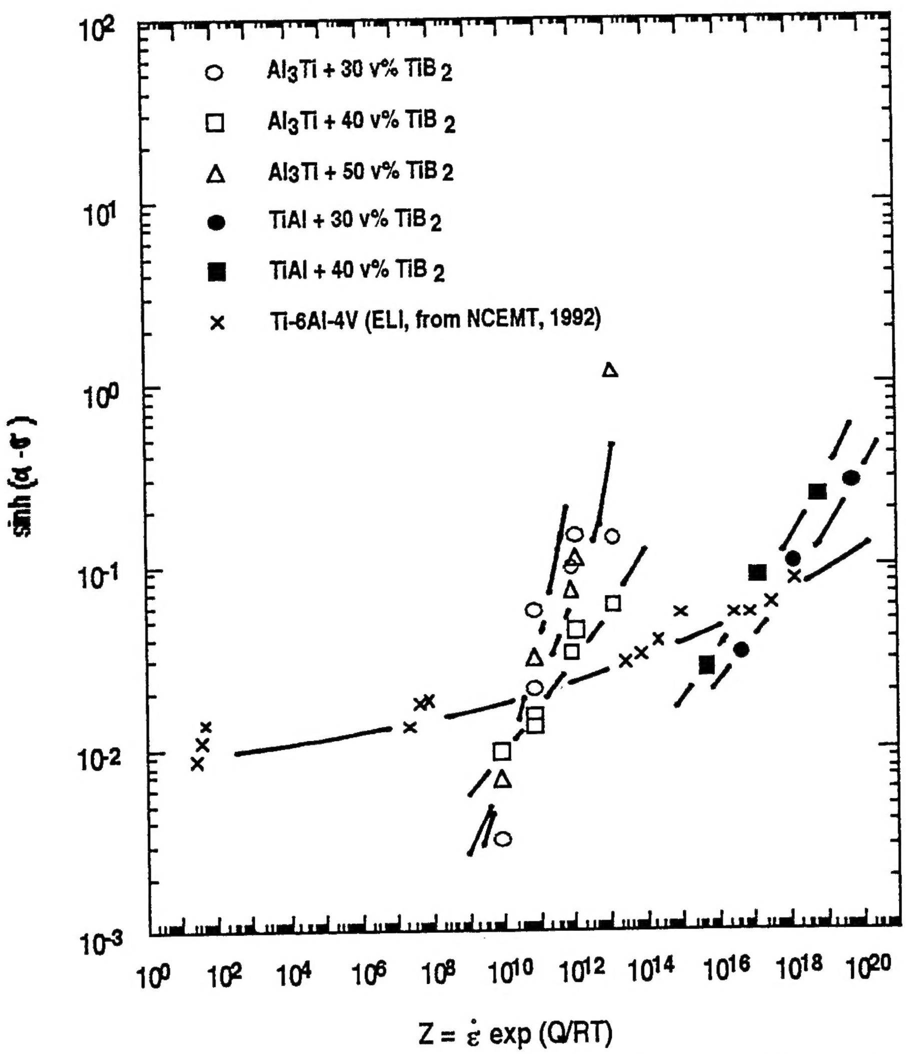

Figure 3-2. High temperature deformation of Ti-6Al-4V, and Al_3Ti and TiAl with 30, 40 and 50 v% TiB_2.

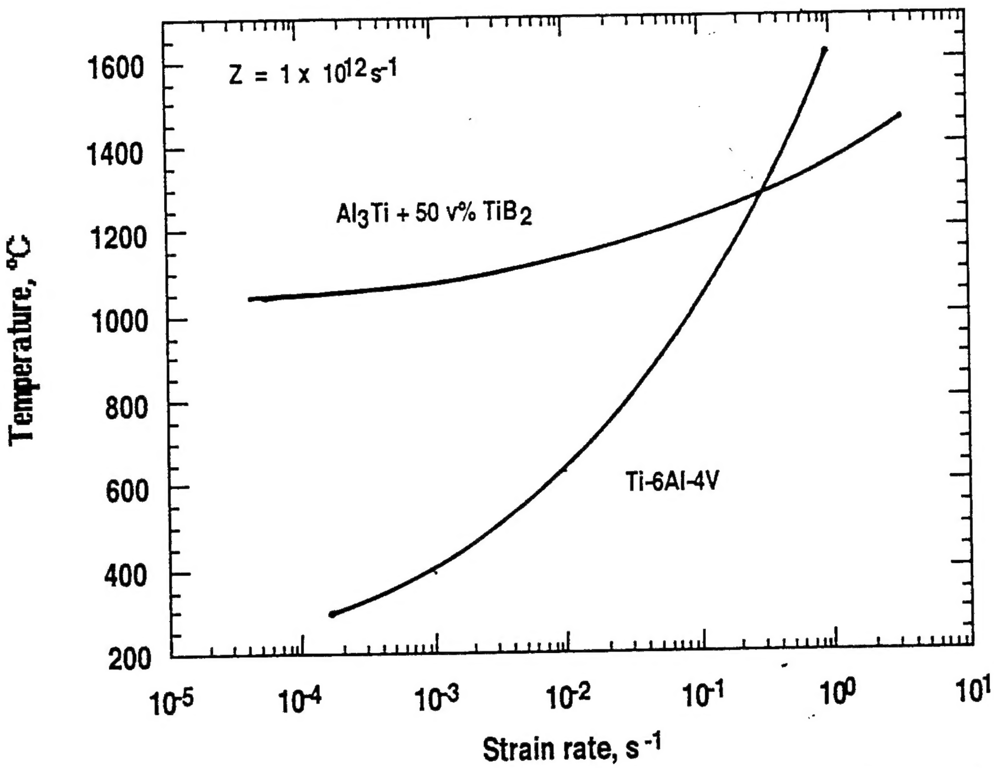

Figure 3-3. Flow behavior at equal Z, Zener-Holloman constant, and stress for Ti-6Al-4V, and Al_3Ti with 50 v% TiB_2. The intersection points defines the conditions for co-deformation processing.

4.0 PLANNED ACTIVITIES

Discussions will continue with Pratt and Whitney and Dynamet to define the MRC materials and properties required to meet advanced naval propulsion system requirements, and to specify components which would serve as candidates for MRC materials insertion. In addition, model development will continue and will be supported by characterization of MRC constituent materials.